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On some aspects of thermoluminescence glow curves

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Abstract : It is shown that for a thermoluminescence (TL) glow peak, to a good approximation the quantity, $I_m T_m^2$ (I_m = peak intensity, T_m = peak temperature) is proportional to n_0, the initial number of trapped electrons for all orders of kinetics. This result can be of significance in dating and dosimetric applications of TL.

Keywords : Thermoluminescence, order of kinetics, dosimetry and dating.

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1. Introduction

For dosimetric and dating applications [1, 2] of thermoluminescence (TL), the basic quantity or parameter of interest is n_0, the initial number of trapped carriers. Again, n_0 is generally taken as proportional to the absorbed dose of radiation. Hence, attempts have been made to identify the possible aspects of TL glow curves exhibiting experimentally tractable dependence on n_0, for example, the area under the glow curve which is proportional to n_0, and the dependence of peak intensity I_m on n_0. The basic theoretical idea behind the pleateau test [1] is also to sort out an aspect of TL glow curve, which exhibits linear dependence of n_0. For TL curves following first order kinetics, it is straight forward to provide the theoretical justification of the plateau test. But for the non-first order kinetics, one does not have the clear theoretical justification for the plateau test.

In this communication, we present a simple experimentally observable feature of the TL glow curve of any order of kinetics which exhibits linear dependence on n_0.

2. Variation of $I_m T_m^2$ with irradiation dose

We start with the general expression of TL (low intensity) for general order given by Chen [3] :

$$I(T) = Nf^b s \exp(-E/kT) \left[1+(b-1)(s/\beta)f^{b-1} \int_o^T \exp(-E/kT')dT' \right]^{-b/(b-1)} \quad (1)$$

where the symbols have their usual significance. $f = n_0/N$ is the initial filling fraction, N is the total number of traps and s is the pre-exponential factor in units of $\sec^{-1}$. The maximum glow intensity I_m occurs at a temperature T_m which satisfies the equation

$$1 + (b-1)(s/\beta)f^{b-1} \int_o^{T_m} \exp(-E/kT)dT$$

$$= b(ks/E\beta)f^{b-1}T_m^2 \exp(-E/kT_m). \quad (2)$$

From eqs. (1) and (2) we have for the peak intensity I_m.

$$I_m = I(T_m) = Ns \exp(-E/kT_m) \left[b(ks/E\beta)T_m^2 \exp(-E/kT_m)\right]^{-b/(b-1)} . \quad (3)$$

Defining the dimensionless quantity $U_m = \frac{E}{kT_m}$, the above eq. (2) can also be written as

$$1 = \frac{s}{\beta} f^{b-1} \frac{T_m}{U_m} e^{U_m} \gamma(U_m), \quad (2a)$$

where.
$$\gamma(U_m) = b-(b-1)\frac{U_m}{T_m}e^{U_m}\int_o^{T_m} e^{E/kT}dT$$

$$= b-(b-1)\, U_m e^{U_m} E_2(U_m). \quad (4)$$

in which $E_2(U_m)$ is the standard second exponential function [4] defined as

$$E_2(U_m) = U_m \int^{\alpha} u^{-2}e^{-u}du = \frac{1}{T_m}\int^{T_m} e^{-E/kT}dT.$$

Eliminating the physically not-so-well-defined parameter s between eq. (3) and eq. (2a) we obtain

$$I_m T_m^2 = n_o \frac{\beta E}{k} \left[b^{-b}\, \gamma(U_m)\right]^{\frac{1}{b-1}}. \tag{5}$$

This result is exact in the sense that it is deduced from the general equation (1) without making any approximation. For the first order kinetics [5] it is straight forward to write [6]

$$I_m T_m^2 = n_o\, (\beta E / k). \tag{6}$$

For the general order kinetics, using the well known asymptotic expansion for $E_2(U_m)$ [4]

$$E_2(U_m) = e^{-U_m}\left[\frac{1}{U_m} - \frac{2}{U_m^2} + \frac{6}{U_m^3} - \ldots\ldots\right],$$

we have

$$\gamma(U_m) = 1 + (b-1)\left(\frac{2}{U_m} - \frac{6}{U_m^2} + \ldots\ldots\right). \tag{7}$$

Thus, for $U_m >> 1$, we may approximate $\gamma(U_m) \approx 1$ in eq. (5) to get

$$I_m T_m^2 \simeq n_o \left[(E\beta / k)\, b^{-b/(b-1)}\right]. \tag{8}$$

Making the usual assumption [7] that n_o is proportional to the irradiation dose D, a plot of $I_m T_m^2$ against D will give a straight line. It may be noted that this linear dependence between the experimentally observable quantity $I_m T_m^2$ and the applied dose holds for all orders of kinetics. Hence it provides an order-independent way of estimating the applied dose and we believe that this simple result will be of interest to those working in TL dosimetry and dating.

3. Discussions

We have a rough check of the experimental validity of the above result by taking the values of I_m and T_m of the glow curves of Sodalite 1 recorded at various doses of X-irradiation [8] which are shown in Figure 1. The dose of irradiation is given in terms of time of irradiation. A plot of $I_m T_m^2$ against irradiation doses is displayed in Figure 2, which shows a good linearity for not too high doses. The departure from linearity for high doses is actually the expected saturation effect.

Another significant aspect of the TL glow curve is the variation of I_m with f or n_o. For the first order kinetics, I_m varies linearly with n_o and for the second order kinetics, Chen *et al*

[9] have obtained slightly superlinear variation. We discuss below the variation of I_m with f or n_o for the general order kinetics.

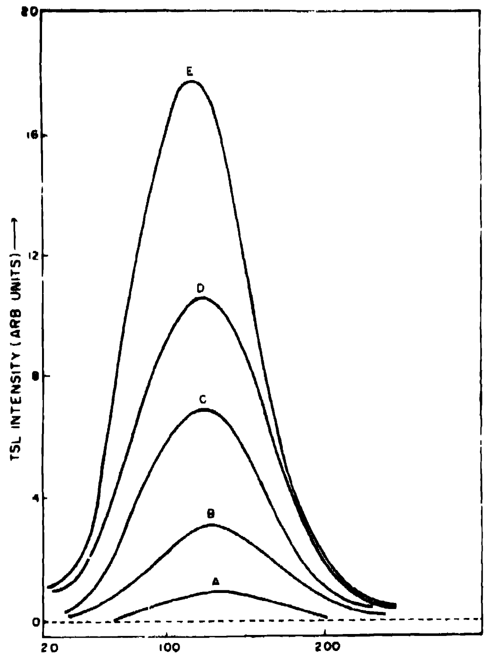

Figure 1. TL curves of Sodalite I, curves A, B, C, D and E are respectively for 5, 10, 20, 30 and 60 sec of room temperature X-irradiation respectively

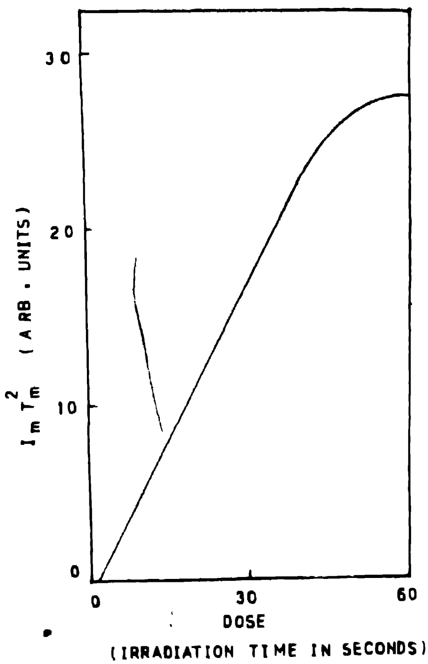

Figure 2. Plot of $I_m T_m^2$ against dose (D) expressed in terms of time of irradiation for glow curves of Sodalite I depicted in Figure 1.

Eq. (2a) can be rewritten as

$$f^{1-b} = \frac{s}{\beta}\left(b\,\frac{kT_m^2}{E}\,e^{-E/kT_m} - (b-1)\int_o^{T_m} e^{-E/kT}dT \right)$$

from which it can be easily shown that

$$\frac{dT_m}{df} = \frac{\beta}{s}\,\frac{(1-b)f^{-b}}{(2b+U_m)}\,U_m e^{U_m}.$$

Eliminating β/s with the help of eq. (2a) we have

$$\frac{dT_m}{df} = \frac{(1-b)\,(U_m)}{(2b+U_m)}\,\frac{T_m}{f}. \qquad (9)$$

Next, from eq. (3) it is straight forward to show that

$$\frac{dI_m}{dT_m} = \frac{(2b + U_m)}{(1 - b)} \frac{I_m}{T_m}. \tag{10}$$

From the last two equations we get

$$\frac{dI_m}{df} = \frac{dI_m}{dT_m} \frac{dT_m}{df} = \gamma(U_m) \frac{I_m}{f}. \tag{11}$$

These eqs. (9–11) are all exact as these have been deduced from the master equation (1), without making any approximation. From eq. (9), it follows that $\frac{dT_m}{df}$ is positive for $b < 1$ and negative for $b > 1$. This means that as f increases, T_m would shift forward for $b < 1$ and backward for $b > 1$.

Chen *et al* [9] deduced eq. (11) for $b = 2$. (For $b = 2$ the quantity $\gamma(U_m)$ reduces to that of Chen *et al* [9]).

Eq. (11) shows that $\frac{dT_m}{df}$ is always positive, hence I_m would increase as f increases.

We note that $\gamma(U_m)$ is a function of f as U_m is a function of f. If $\gamma(U_m)$ is a slowly varying function of f such that

$$\left|\frac{d}{df}\left(\ln\gamma(U_m)\right)\right| << \left|\frac{1}{f\ln f}\right|, \tag{12a}$$

then the above eq. (11) can be integrated to give

$$I_m \sim f^{\gamma(U_m)}. \tag{12b}$$

Recalling the asymptotic expression for $\gamma(U_m)$ given in eq. (7), eq. (13) gives superlinear/sublinear variation of I_m for $b > 1 / b < 1$. Of course, for the first order kinetics eq. (11) is simply $\frac{dI_m}{I_m} = \frac{df}{f}$ which immediately gives linear variation of I_m with f.

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